



Poster Abstract: Smartphone-based Blood Perfusion Assessment for Ulcer Care

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ABSTRACT

In this paper, we propose a transformative solution that uses a low-cost light sensor and commodity smartphone to support fast self-assessment of blood perfusion of ulcer regions in daily life. By harnessing the knowledge of light polarization, our system can “see-through” the skin to quantify the spatio-temporal properties of subdermal vasculature in terms of pulsation and hemoglobin. Our evaluation results show that our system can achieve 78.6% accuracy to detect poor and good blood perfusion.

CCS CONCEPTS

• **Human-centered computing** → **Ubiquitous and mobile computing systems and tools.**

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1 INTRODUCTION

Chronic ulcers (e.g., pressure ulcers, and diabetic ulcers) afflict approximately 6.5 million Americans [1]. The treatment expenses for chronic ulcers are more than \$25 billion annually [1]. Revascularization surgery is one of the most effective therapies for chronic ulcers, which restores in-line arterial blood flow to ulcers [2]. However, perfusion to a region of tissue loss may be insufficient [2] for patients with diabetics or peripheral artery disease. Therefore, it is critical to examine changes after revascularization and investigate whether perfusion has been sufficiently repaired, which would significantly benefit ulcer management.

Current practice in tissue perfusion monitoring for after-surgery management is based on hospital-centered solutions, which are mainly categorized into three categories: 1) physical assessment of wound size and color; 2) contrast injection [3], e.g., contrast-enhanced ultrasound, and MRI perfusion imaging; 3) transcutaneous oxygen pressure (TcPO₂) for measuring tissue oxygenation [3]. However, these solutions largely rely on clinical devices and vascular surgeons, which require long time hospitalization and generate huge medical burden. Recent studies explore non-clinical solutions, such as infrared camera-based imaging systems and portable

ultrasound pulsed-wave Doppler devices [3], but they are either expensive or insensitive in evaluating distal perfusion.

In this paper, we propose a sensor-based low-cost and home-used approach for blood perfusion monitoring. By harnessing the knowledge of light polarization, we first built a sensing system that consists of low-cost light sensor and commodity smartphone to collect video data revealing the subdermal vasculature of the wound region. Then, we extract blood pulsatile intensity distribution and quantify the Oxy/Deoxy-Hemoglobin to evaluate the blood perfusion of wound region. Finally, a preliminary study is conducted to validate the feasibility of our approach for ulcer care.

2 METHODOLOGY

2.1 Light Polarization-based Imaging

Our sensing platform consists of the light source, the smartphone built-in camera, and the polarizer, as shown in Figure 1. When the light is emitted from the light source, it first passes through a polarizer. After the polarized light reaches the skin surface, some go to the internal tissue, and others are reflected. The reradiated light from the internal tissue becomes unpolarized and can successfully pass through the polarizer ahead of the camera, whereas the reflected light from the surface tissue is impeded and will not enter into the camera. Finally, we can get the video data that reveals the subdermal vasculature of the wound region.

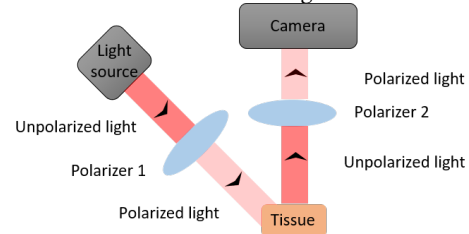


Figure 1: Light polarization theory for vasculature imaging.

2.2 Blood Pulsatile Extraction

Heart pumping leads to pulsatile blood volume propagating throughout the body tissue, resulting in the absorption modulation of the light propagating within the skin. The modulation in turn leads to the intensity modulation of light reflected from the skin tissue. To remove the background noises in the recorded intensity modulation, we perform fast Fourier transform on time-series intensity variation of each location. The area of palm is located by selecting the locations where the intensive varies between 0.8-2.2 Hz. For the selected palm area, the intensity is calculated by the energy of the peak found between 0.8-2.2 Hz. By considering the frequency of heartbeats, this method outperforms the segmentation based on binarization masking.

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2.3 Oxy/Deoxy-Hemoglobin Quantification

We selected 950 nm (with almost the same absorption) and 650 nm (differ notably in absorption between HbO₂ and Hb) as the target wavelengths to estimate changes in light absorption and infer Oxy/Deoxy-Hemoglobin information. Based on the modified Beer-Lambert law, the change in HbO₂ and Hb concentration can be derived as:

$$\Delta c^{HbO_2} = \frac{\Delta A_{950} - kA_{650}}{l(\epsilon_{950}^{HbO_2} - k\epsilon_{650}^{HbO_2})} \quad (\text{where } k = \epsilon_{950}^{Hb} / \epsilon_{650}^{Hb})$$

$$\Delta c^{Hb} = \frac{\Delta A_{950} - kA_{650}}{l(\epsilon_{950}^{Hb} - k\epsilon_{650}^{Hb})} \quad (\text{where } k = \epsilon_{950}^{HbO_2} / \epsilon_{650}^{HbO_2})$$

where ΔA is the change in light absorption, l is the length of light interaction path, ϵ is the absorption extinction coefficient. By performing such computation at each pixel in the video, the spatiotemporal changes of hemoglobin concentrations within the dynamic blood perfusion can be obtained.

2.4 Blood Perfusion State Detection

We fed the pulsation distribution and hemoglobin distribution to ResNet-18, which has shown superior image understanding capability in practice, to learn and detect the unique blood perfusion pattern for good and poor blood perfusion. The pulsatile intensity distribution, deoxy, and oxy-hemoglobin distributions are aligned together as three channels of the input to the neural network.

3 EVALUATION

3.1 Experiment Setup

Data Collection. We recruit 11 subjects to emulate two cases of blood perfusion: 1) a healthy palm with normal blood perfusion; 2) obstructed blood flow on the palm with the cuff on the arm. The hardware setup is shown in Figure 2. For blood pulsatile extraction, subjects are requested to put their left and right palms successively under the 532 nm light source illumination for 30 seconds, and we record the video. For Hemoglobin quantification, subjects are requested to put their left and right palms under the 950 nm and 650 nm light source illumination for 5 seconds, respectively, and we record the corresponding video for each. The device is placed directly above the palm from a distance of 20 cm.

Data Partition. To infer the blood pulsatile distribution, we divide the recorded video into multiple segments (samples) with a length of 3 seconds. In total, we can obtain 200 cuff samples and 200 uncuff samples. To infer hemoglobin/deoxy-hemoglobin distribution, the videos under 950 nm and 650 nm light illumination are in contrast by frames. With the video frame rate of 20, we can get 2000 cuff samples and 2000 uncuff samples in total.

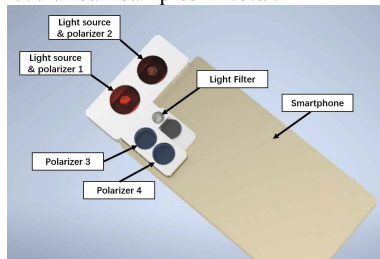


Figure 2: Hardware setup using a smartphone and compact light module.

3.2 Blood perfusion Assessment Results

Blood Pulsatile Analysis: Higher intensity represents stronger pulsatile signals. As shown in Figure 3, for normal palms, the middle and ring fingers show stronger pulsatile signals than other regions due to the abundant and active capillary, which indicates good blood perfusion. In contrast, for cuffed palms, the pulsatile signals are weakened averagely on the palm, so it suggests very little blood passes through the vasculature.

Oxy/Deoxy-Hemoglobin Analysis: Figure 4 shows that a normal palm has relatively low deoxy-hemoglobin and high oxy-hemoglobin. In contrast, the cuffed palm demonstrates relatively high deoxy-hemoglobin and low oxy-hemoglobin, which indicates the blood hardly passes through the palm, i.e., poor blood perfusion.

Good/poor Perfusion Detection: The results show that blood perfusion state detection accuracy, recall, and precision are 78.6%, 81.2%, and 77.5%, respectively.

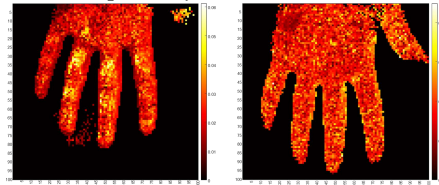


Figure 3: The blood pulsatile intensity distribution. Left: uncuff; Right: cuff.

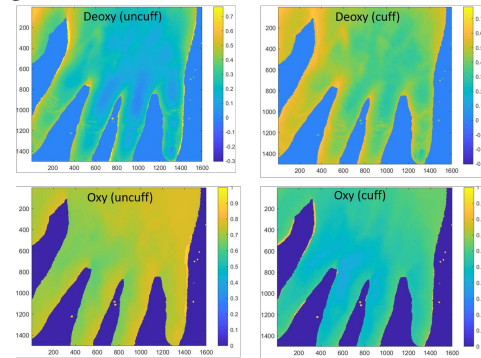


Figure 4: The Deoxy- and Oxy- hemoglobin distribution. Left: uncuff; Right: cuff.

4 CONCLUSION

In this paper, we develop a blood perfusion assessment tool for ulcer management based on a smartphone and compact light module. The blood perfusion is quantified from pulsation distribution and hemoglobin distribution. In the future, we will recruit patients with true ulcers to validate the effectiveness of our approach.

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